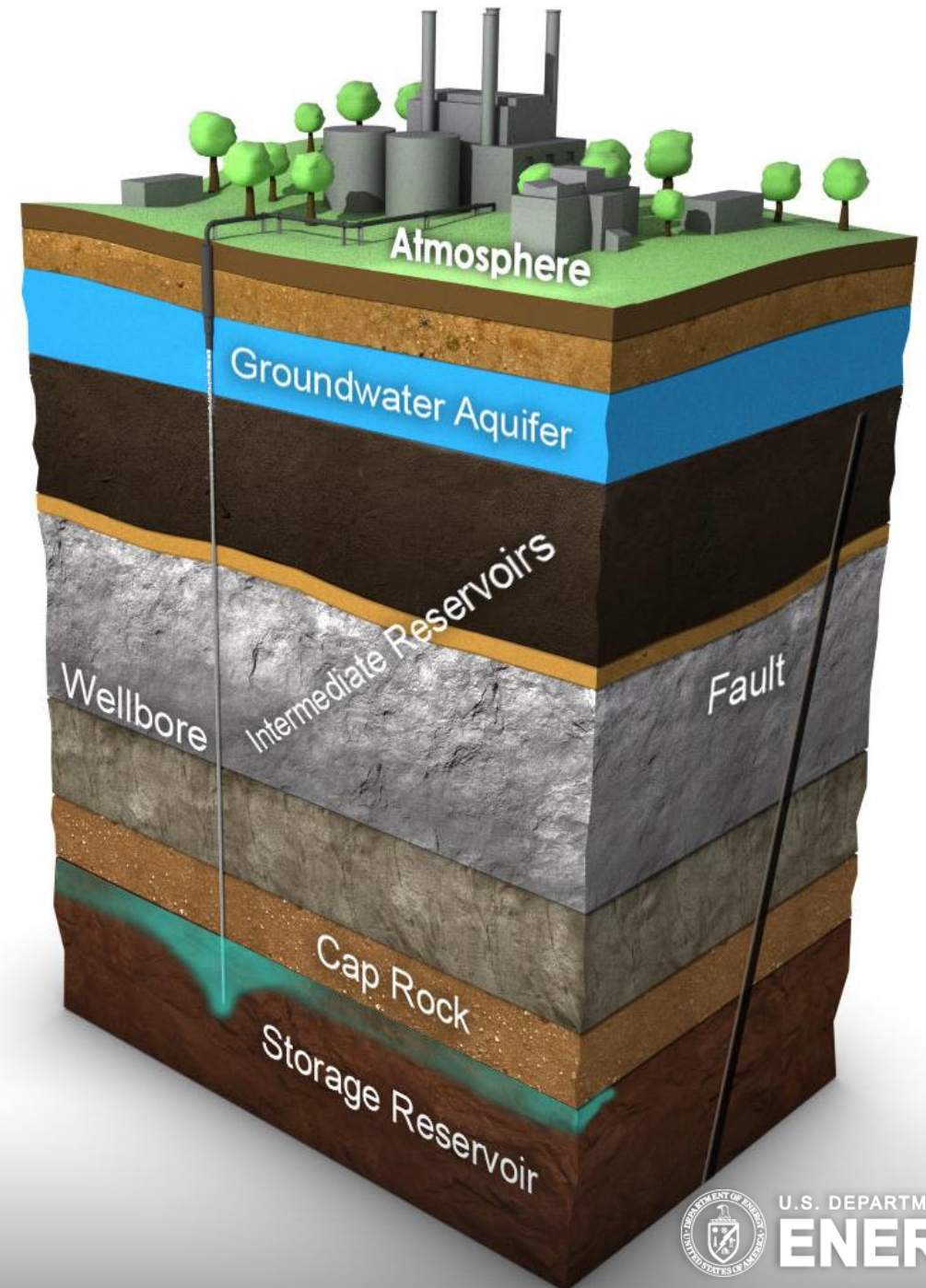


# Assessing Geomechanical Risks at GCS Sites Using the State of Stress Assessment Tool (SOSAT)

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U.S. DEPARTMENT OF  
**ENERGY**

# Outline

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- What is geomechanical risk?
- What is SOSAT?
- **Example: using SOSAT to estimate risk based on:**
  - Frictional faulting (stress polygon)
  - Mini-frac stress measurement (wireline-based)
  - Absence of breakout (image log)

# What is Geomechanical Risk?

- **Leakage caused by unintentional hydraulic fracturing**
  - Occurs when the pore fluid pressure exceeds the minimum principal stress
  - Can occur in reservoir or the caprock
- **Induced seismicity**
  - Caused by change in stress on fault induced by elevated pore pressure
  - Can be caused directly by elevated pore pressure on fault
  - Can be caused indirectly by changes in stress even if local pore pressure is not elevated

# What is SOSAt?

## State of Stress Assessment Tool (SOSAT)

- Allows user to input a wide variety of observations relevant to state of stress
- Computes probability distribution of the stress tensor at a point in the subsurface
- Can be applied to reservoir or surrounding formations
- GUI supports some features but there are some only supported through a Python interface

State-of-Stress Assessment Tool

File

Reservoir Properties | Regional Stress Info | Stress Measurement | Calculation and Plot

Median friction coefficient: 0.7

Standard deviation of logarithm of fault friction coefficient: 0.15

Maximum possible friction coefficient: 1.5

Reservoir depth: 2344 meters

Pore pressure gradient: 9.81 MPa/km

Average overburden density: 2500.0 kg/m<sup>3</sup>

Maximum injection pressure: 50 MPa

\*Hover over a label to see its full description here.

Revert Parameters to Defaults Cancel Save

## SOSAT is Now on GitHub ([github.com/pnnl/SOSAT](https://github.com/pnnl/SOSAT))

pnnl/SOSAT: State of Stress Analysis Tool

github.com/pnnl/SOSAT

LICENSE added a project skeleton. 27 days ago

MANIFEST.in added a project skeleton. 27 days ago

Makefile added a project skeleton. 27 days ago

README.rst updated README.rst 1 minute ago

requirements\_dev.txt updated comments for StressState, restructured ... 8 days ago

setup.cfg fixed some typos introduced into setup.cfg and b... 10 days ago

setup.py updated comments for StressState, restructured ... 8 days ago

tox.ini trying to eliminate the flag-name from coveralls ... 10 days ago

Contributors 2

jeff788

devcentral-pnnl PNNL De...

Languages

Python 90.8%

Makefile 9.2%

README.rst

### SOSAT

pypi package: 0.1.0

build: passing

docs: passing coverage: 99%

The State of Stress Analysis Tool (SOSAT) is a Python package that helps analyze the state of stress in the subsurface using various types of commonly available characterization data such as well logs, well test data such as leakoff and minifrac tests, regional geologic information, and constraints on the state of stress imposed by the existence of faults and fractures with limited frictional shear strength. It employs a Bayesian approach to integrate these data into a probability density function for the principal stress components.

- Documentation can be found at <https://SOSAT.readthedocs.io>.
- SOSAT is free software released under a BSD license

Funding to develop SOSAT was provided by the National Risk Assessment Partnership (NRAP) in the U.S. DOE Office of Fossil Energy under DOE contract number DE-AC05-76RL01830.

# Does stress uncertainty matter?

- **How will the information be used?**
  - Wellbore stability
  - Fracture initiation
  - Fracture height growth
  - Induced seismicity
- **What is the consequence of an error?**
  - Inconvenience
  - Delay
  - Lost revenue
  - Elevated costs
  - Environmental damage
  - Loss of life

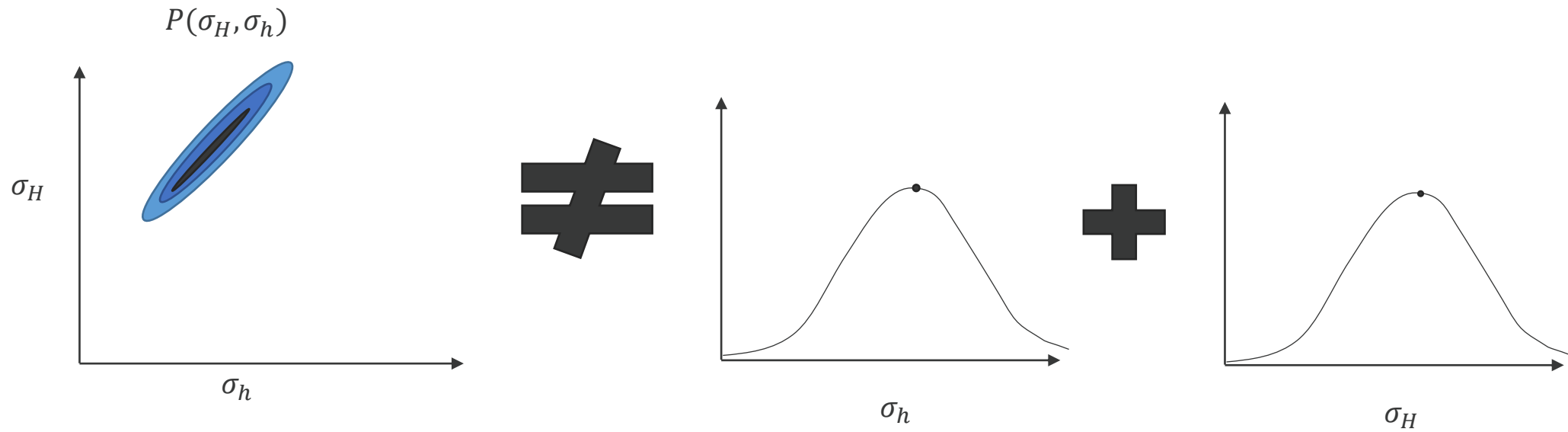


Increasing importance  
of UQ

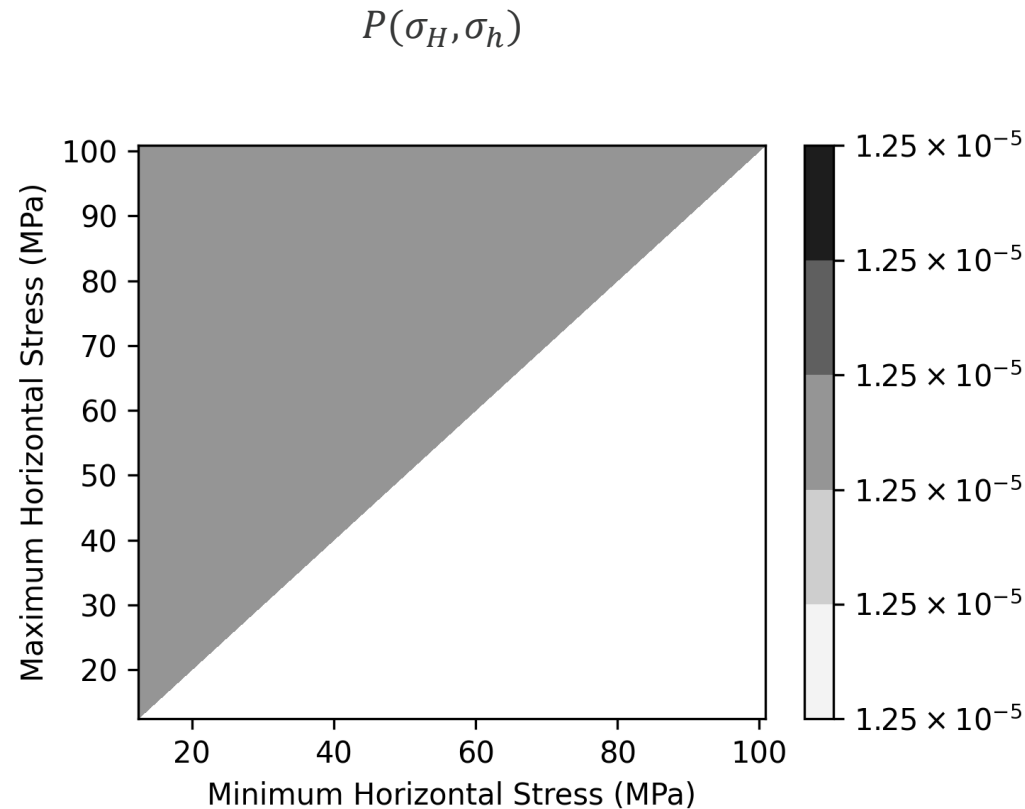
# Applying Statistics to Tensors

Statistically, stress (and other tensors) should be thought of as a joint probability distribution of magnitudes and directions

There is often a correlation between principal stress components, so they cannot be treated as independent



# Prior Stress State Assumption

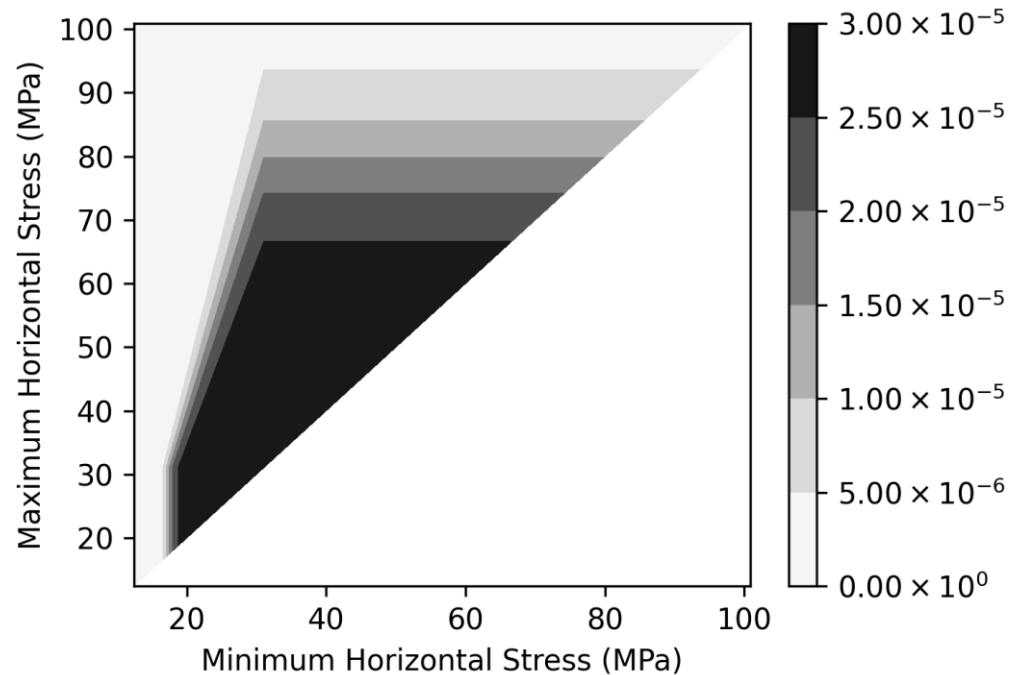


Begin with posterior assumption that all stress states where  $\sigma_H > \sigma_h$  and both are compressive have equal probability



# Frictional Faulting Constraint

$$P(\sigma_H, \sigma_h)$$

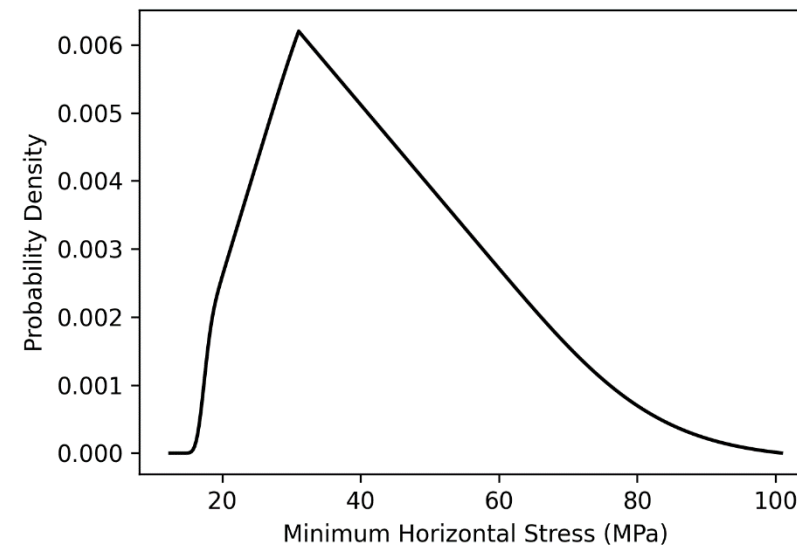


Assert that stress cannot be larger than rock strength, which is assumed to be governed by frictional strength of faults and fractures

$$P(D|\sigma_H, \sigma_h) = 1 - \frac{1}{2} \operatorname{erfc} \left[ -\frac{\ln \mu_c - \mu_o}{\sigma_\mu \sqrt{2}} \right]$$

$\mu_c$  friction coefficient that would cause failure at a given stress state

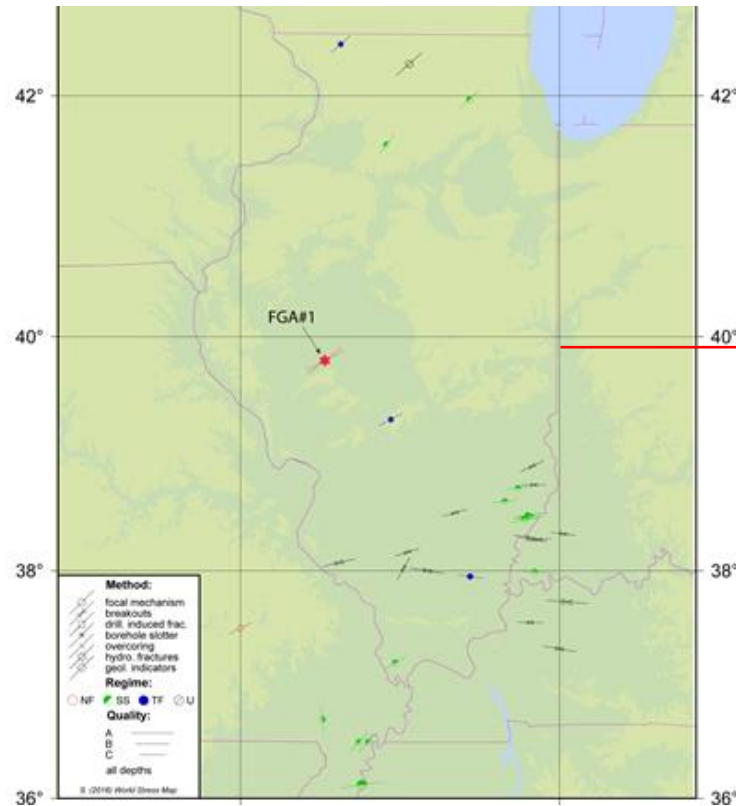
$\mu_o$  mean of the lognormal distribution for friction



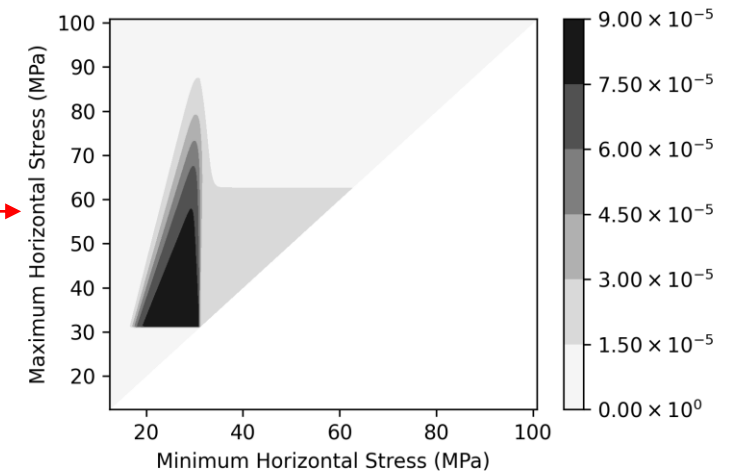
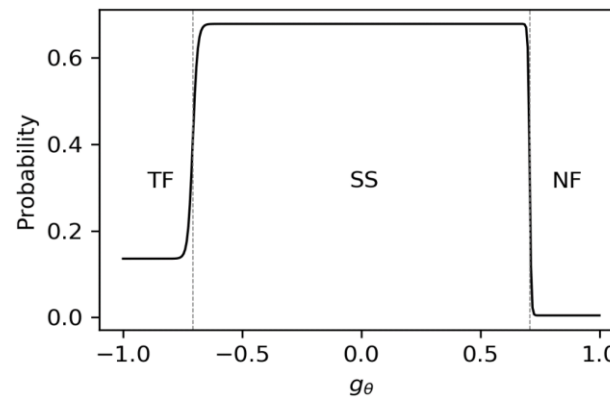


# Regional Stress Observations

Most stress indicators in the area suggest a strike-slip state of stress, with some possibility of thrust faulting

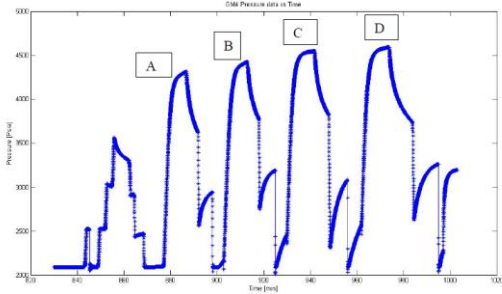


World Stress Map Database

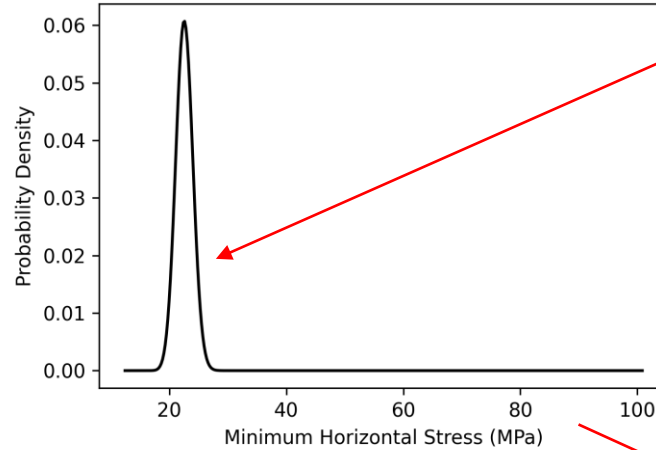
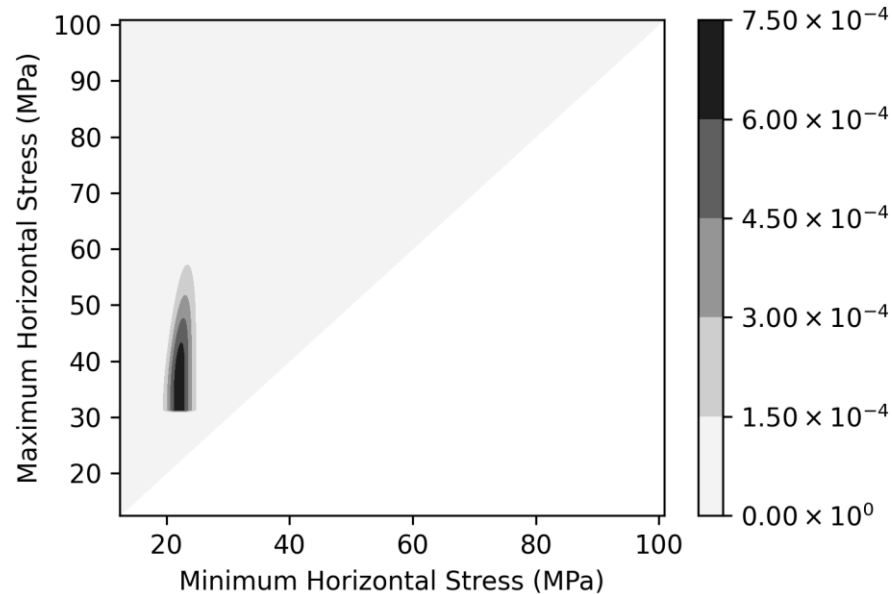


# Minimum Principal Stress Measurement

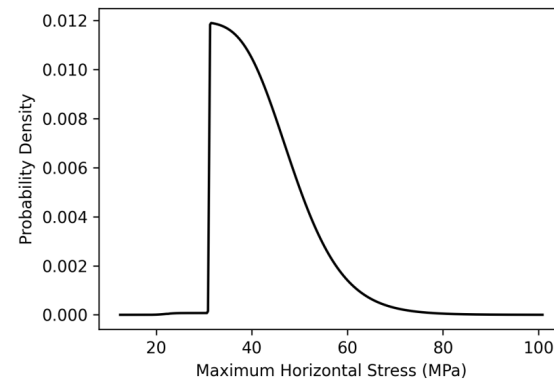
## Mini-frac measurement



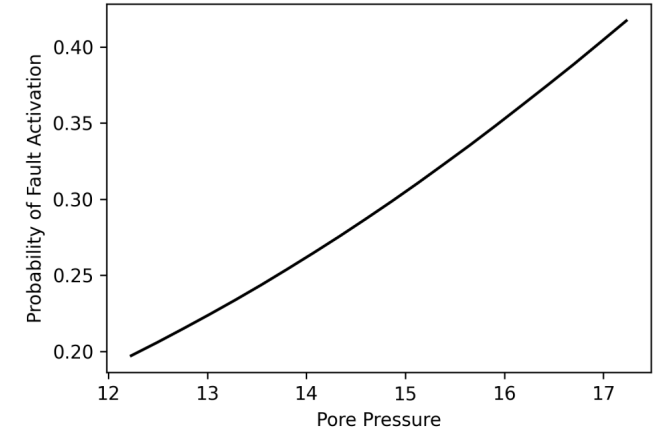
Add mini-frac stress measurement with normal distribution with mean of 22.1 MPa and standard deviation of 1.5 MPa



Risk of hydraulic fracturing is governed by this



Risk of fault activation is governed by both stresses



# Constraint by Absence of Breakout

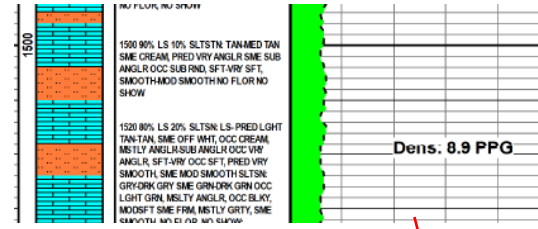
Image Logs



Core Tests



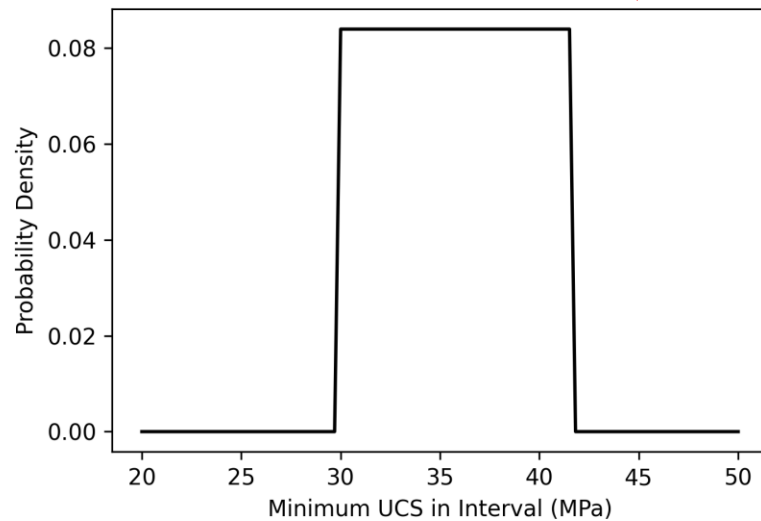
Mud Logs/Drilling Reports/  
MWD Data



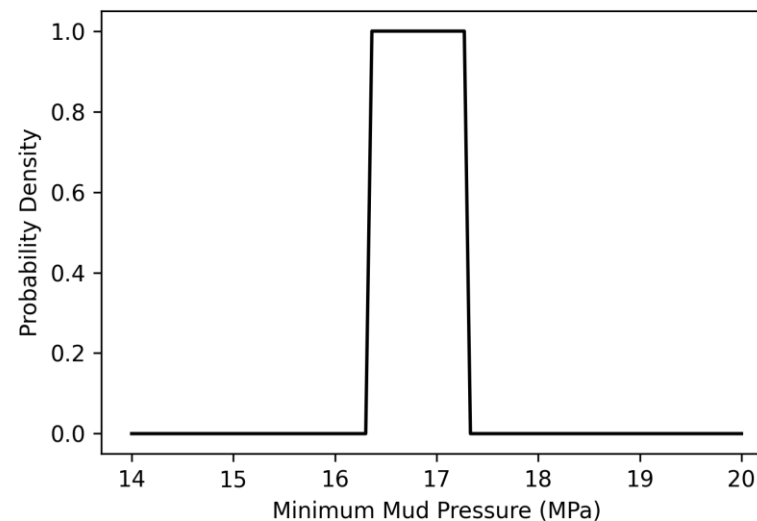
Add constraint based on the absence of breakouts and uncertainties in formation and mud properties

Formation of breakout depends on  $\sigma_h$ ,  $\sigma_H$ , and:

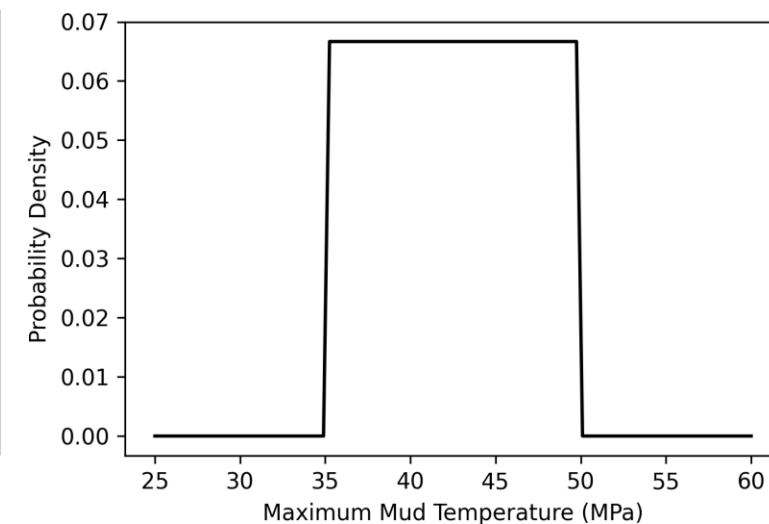
Minimum rock strength



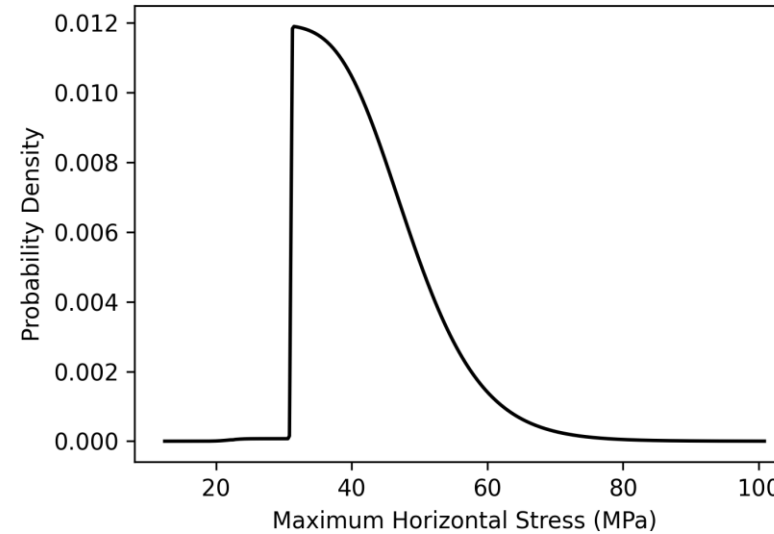
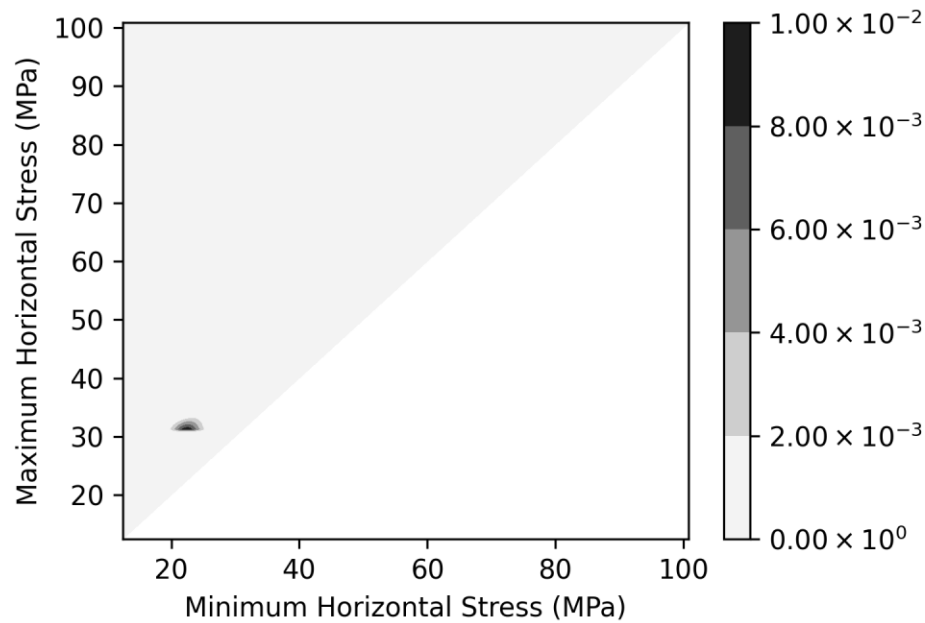
Minimum mud pressure



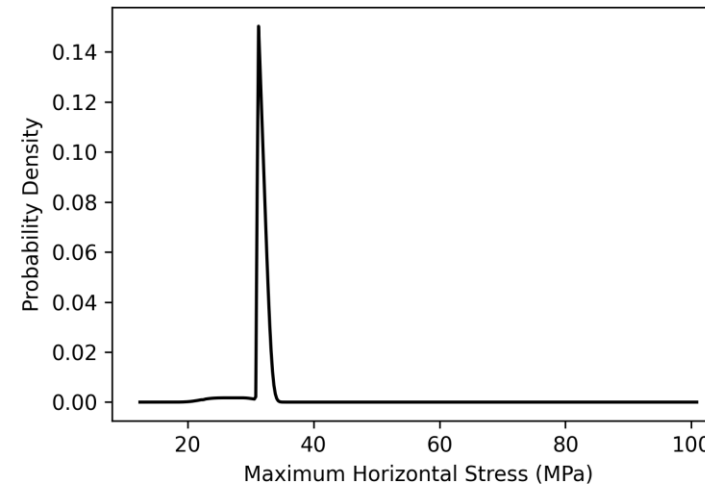
Maximum mud temperature



# Constraint by Absence of Breakout



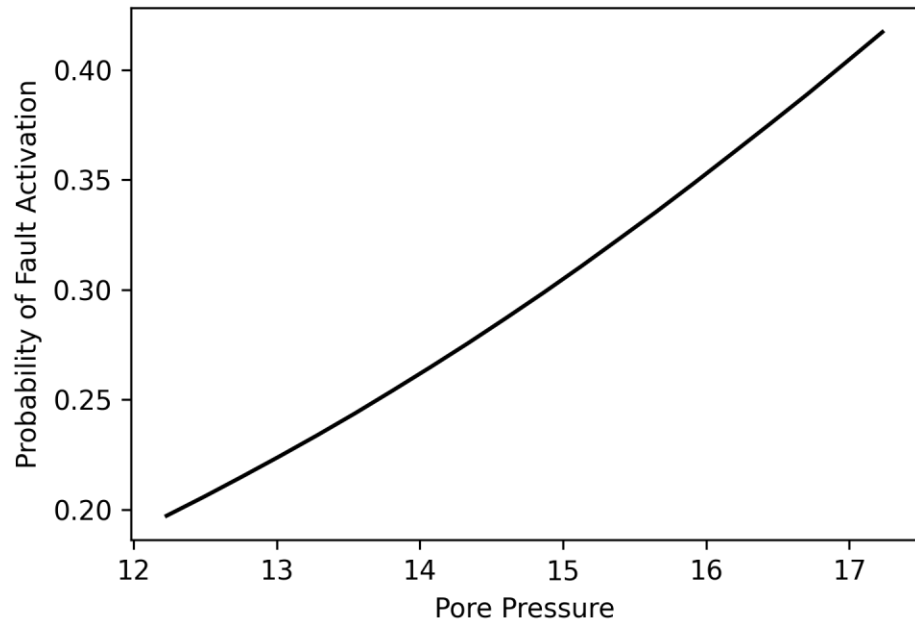
Without breakout constraint



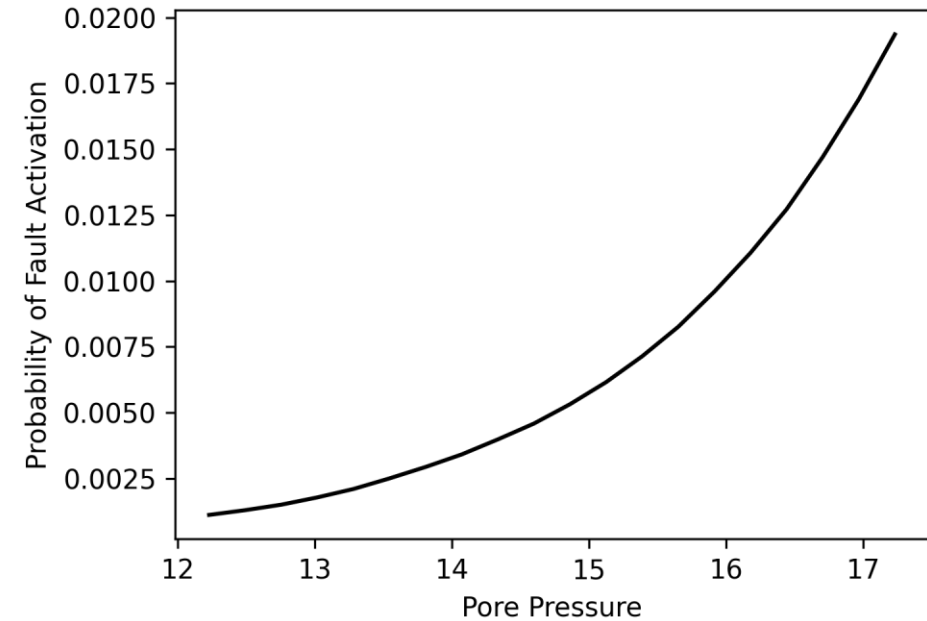
With breakout constraint

# Constraint by Absence of Breakout

Risk of fault activation without breakout analysis



Risk of fault activation with breakout analysis



# Future Plans/Learn More

- **2D Mapping along a formation**
  - Develop support for earthquake focal mechanisms
  - Automate pulling data from World Stress Map Database
- **Develop web-based GUI**

Download GUI and User's Manual:

<https://edx.netl.doe.gov/nrap/state-of-stress-analysis-tool-sosat/>

Tool User Forum:

<https://edx.netl.doe.gov/workspace/forum/nrap-tools>

Download/Install from GitHub or PyPi:

<https://github.com/pnnl/SOSAT>